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نموذج رقم (١٨)
اقرار والتزام بالمعايير الأخلاقية والأمانة العلمية
وقوانين الجامعة الأردنية وأنظمتها وتعليماتها
لطلبة الماجستير

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عنوان الرسالة: **Impact of Crop Type and Soil Moisture Content on Radon Emission from Soil**

اعلن بأنني قد التزمت بقوانين الجامعة الأردنية وأنظمتها وتعليماتها وقراراتها السارية المفعول المتعلقة باعداد رسائل الماجستير عندما قمت شخصيا" باعداد رسالتي وذلك بما ينسجم مع الأمانة العلمية وكافة المعايير الأخلاقية المتعارف عليها في كتابة الرسائل العلمية. كما أنني أعلن بأن رسالتي هذه غير منقولة أو مستلة من رسائل أو كتب أو أبحاث أو أي منشورات علمية تم نشرها أو تخزينها في أي وسيلة اعلامية، وتأسيسا" على ما تقدم فانني أتحمل المسؤولية بأنواعها كافة فيما لو تبين غير ذلك بما فيه حق مجلس العمداء في الجامعة الأردنية بالغاء قرار منحي الدرجة العلمية التي حصلت عليها وسحب شهادة التخرج مني بعد صدورها دون أن يكون لي أي حق في التظلم أو الاعتراض أو الطعن بأي صورة كانت في القرار الصادر عن مجلس العمداء بهذا الصدد.

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IMPACT OF CROP TYPE AND SOIL MOISTURE CONTENT ON RADON EMISSION FROM SOIL

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This Thesis was Submitted in Partial Fulfillment of the Requirements for the Master's Degree of Science in Land, Water and Environment

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COMMITTEE DECISION

This thesis (Impact of Crop Type and Soil Moisture Content on Radon Emission from Soil) was successfully defended and approved on May 5th , 2011.

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Dedication

To my father and mother who supported me and have lightened my life with their support, love, encouragement and guidance.

And to

My beloved husband for his tolerance over the past three years of dedication to research and study whereby he had to manage most of our joint life independent of my assistance.

And to

My brothers and sisters

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF ABBREVIATIONS

Symbol	Description
U	Uranium
^{232}Th	Thorium
Bq	Becquerel
^{222}Rn	Radon
^{220}Rn	Thoron
^{219}Rn	Actinon
Po	Polonium
Pb	Lead
Ra	Radium
UNSCEAR	United Nations Scientific Committee on the Effect of Atomic Radiation
D	Effective diffusion coefficient
C	Concentration of ^{222}Rn (activity/volume)
λ	Decay constant of ^{222}Rn (2.1×10^{-6} s^{-1})
Q	The source term for ^{222}Rn
R	Specific activity of ^{226}Ra
ρ_b	Bulk density of the soil (g cm^{-3})
E	^{222}Rn emanation coefficient
φ	Soil porosity
CR-39	Brand name for allyle diglycol polycarbonate
SSNTD	Solid State Nuclear Track Detector
PVC	Polyvinyl chloride
kBq	kilo Becquerel
C_o	^{222}Rn activity of calibration champer (90 kBq/m^3)
t_0	Calibration exposure time (48 hours)

Symbol	Description
ρ_o	number of α-hits per unit area of the calibrated CR-39 paper (3.309×10^4 hits/cm^2)
$\bar{X}$	Average number of hits
A	The area of the microscope field (cm^2)
$\theta v_{F.C}$	Volumetric water content at field capacity (m^3/m^3)
$\theta v_{measured}$	Measured volumetric water content (m^3/m^3)
V_s	Volume of soil (cm^3)
EC_e:	Electrical conductivity (dS m^{-1})
Rh:	Relative humidity
MPa:	Mega pascal
SRL:	Specific root length (cm g^{-1})
RLD:	Root length density (cm cm^{-3})
F	The back diffusion corrected exhalation rate (Bq m^{-2} h^{-1})
Fo	The uncorrected exhalation rate (Bq m^{-2} h^{-1})
A	The surface area of the sample (m^2)
V	The volume of the void space in the closed chamber (m^3)
Zo	The thickness of the sample in a sealed chamber (m)
ω	The back diffusion constant for a given material (m h^{-1})
k	Soil permeability (m^2)
c	Constant that depends on pore size and shape.
T	The tortuosity
S	The specific surface area
d	Particle diameter

.

IMPACT OF CROP TYPE AND SOIL MOISTURE CONTENT ON RADON EMISSION FROM SOIL

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ABSTRACT

Emission of ^{222}Rn gas from soil has been identified a major source of ^{222}Rn inhalation by public. Site of Russeifa town is located on wastes from old landfill site of phosphate rock mining. The area is known to be heavily polluted with ^{222}Rn. This research was advanced to explore possibility of reducing ^{222}Rn emission from soil to atmosphere by hypothesizing that filling soil pores with moisture and/or changing soil pore size distribution by different plant root systems (pepper, eggplant, alfalfa and barley) would affect ^{222}Rn diffusion from soil to atmosphere. Composite surface soil sample (0-20 cm) known to have high ^{222}Rn emission was collected from Russeifa National Park. The sample was air dried, gently ground to pass 2 mm sieve and stored for later use. Subsamples, 16 kg each were packed in plastic pots (24.5 cm diameter × 26 cm height) at ρ_b 1.3 g cm^{-3}. For each of the above plant species, four pots with replicates were planted in winter season of 2009/2010, with two seedlings of pepper and eggplant or 10 seeds of alfalfa and barley. Each planted pot was replicated four times and irrigated with quantity of tap water high enough to reach field capacity. Each plastic pot was then placed in (1×1×1 m^3) wood frame covered with transparent plastic. Following each irrigation, ^{222}Rn emitted α- particles were detected on weekly basis using time integrated passive radon dosimeters containing CR-39 solid-state nuclear track detector. The dosimeter was hung from the roof of a plastic box and was not covered by any part of plant canopy over all the greenhouse experiment. The effect of soil moisture content on ^{222}Rn emission from soil was also studied. A triplicate soil subsamples, 1 kg, were packed into plastic containers (10 cm diameter × 50 cm height), water was added to each soil subsamples to reach gravimetric moisture content of 0%, 5%, 10%, 15%, 20%, 25% and 30% and ^{222}Rn emission was measured using the dosimeter cups to each CR-39 paper which was attached at 25 cm above the soil surface The surface of each container was covered with a plastic sheet to prevent escape of α-particles. Each setup was left standing for 21 days after which the CR-39 detectors were removed.

Results showed that water content and plant type had a significant effect on ^{222}Rn emission from soil. The radioactivity from emitted ^{222}Rn increased linearly with increasing soil moisture content up to 20% by gravity beyond which radioactivity remain almost at constant value (940 Bq m^{-3}). The results also showed that for all the plant species the ^{222}Rn emission from soil to atmosphere was lower than that of the bare soil. For pepper planted pots ^{222}Rn emission tended to be lower than the other plant species. The order of reducing ^{222}Rn emission was as follows: eggplant> alfalfa> barley.

1. INTRODUCTION

The earth contains numerous radioactive elements, the most abundant of which are radioisotopes of the natural series of uranium (^{238}U), actinium (^{235}U) and thorium (^{232}Th) and their decay products (Azouazi et al., 2001). Trace concentrations of ^{238}U and ^{232}Th are found in most natural rocks. The acidic magmatic rocks such as granite contain, in general, more radioactive elements than sedimentary rocks, and that latter contain more than basic magmatic rocks such as basalt (Al-Bataina et al., 1997). A typical radioactivity of ^{238}U in sedimentary phosphate deposits is about 1500 Bq kg^{-1} of soil (Adam et al., 1995). Here, Bq is one disintegration per second.

Phosphate rock is used worldwide for manufacturing phosphoric acid and various brands of chemical fertilizers. Extraction of phosphate from these sediments results in disturbance of natural earth strata and exposure of subsurface layer to surface and, thus, enhanced emission of radionuclides to atmosphere. Jordan has enormous reserve of phosphate deposits concentrated along a belt extending from north to south (Al-Hwaiti et al., 2005). One of the oldest phosphate mines in Jordan was that near Russeifa city. Phosphate tunnel mining from that site ceased in the 1983 (Jordan Phosphate Mines Company). Land spoils from that site were dumped in a nearby location. However, urban dwellings have encroached to that site and thus, people living there have become subjected to different types of radionuclides emission. For example, Al-Jundi (2002) reported high levels of ^{238}U in soil samples obtained from some locations near urban area in Russeifa city (mean radioactivity of ^{238}U in Russeifa Nation Park was 444.1 Bq kg^{-1}, and 523.2 Bq kg^{-1} of soil in a nearby phosphate dumpsite hill). Kullab et al. (2001) indicated that ^{222}Rn emission of α particles from such a spoil land to atmosphere reached levels beyond these of human

safety e.g. (148 Bq m^{-3} of air as recommended by US EPA). Moreover, Kullab et al. (2001) found that the maximum value of ^{222}Rn radioactivity in air inside homes was 1532.9 Bq m^{-3} of air during winter season. The minimum value was reported during fall season and was 87.3 Bq m^{-3} of air. The overall, mean value of ^{222}Rn radioactivity inside homes of that location was 273.7 Bq m^{-3} of air.

Radon is a naturally occurring, chemically inert, radioactive gas that exists in soil, air and cracks of rocks containing ^{238}U and ^{232}Th. Natural Rn has three isotopes--one from each of the three natural radioactive-disintegration series of uranium, thorium, and actinium .. Radon-222 (3.823-day half-life), the longest-lived isotope, arises in the uranium series. The name radon is sometimes reserved for this isotope to distinguish it from the other two natural isotopes, called thoron (^{220}Rn with half-life 55.6 s) and actinon (^{219}Rn with half-life 4s), because they originate in the thorium and the actinium series, respectively.

Because of its very short half-life, ^{219}Rn is hardly detected in soil air and in adjacent atmosphere. The other two isotopes are represented in the soil gaseous phase but ^{222}Rn (with the longest half-life) is the only isotope that can be detected in the atmosphere and, subsequently, in indoor gases. The short half-life of ^{220}Rn (55.6 s), reduces the possibility for that gas to spread far away from the source. To the contrary, the diffusion length of ^{222}Rn is nearly 100 times greater than that of ^{220}Rn (Jönsson, 1995). This value of the half-life and the gaseous nature of ^{222}Rn allow relatively long migration of the element in both soil empty pores and the atmosphere before its decay. The ^{222}Rn decays to polonium (^{218}Po) by emitting an alpha particle. Thereafter, the progeny decay to ^{214}Po and ^{214}Pb as demonstrated below:

$$^{222}Rn \overset{\alpha}{\rightarrow} {}^{218}Po \overset{\alpha}{\rightarrow} {}^{214}Pb \overset{\beta}{\rightarrow} {}^{214}Bi \overset{\beta}{\rightarrow} {}^{214}Po \overset{\alpha}{\rightarrow} {}^{210}Pb \overset{\beta}{\rightarrow} {}^{210}Bi \overset{\beta}{\rightarrow} {}^{210}Po \overset{\alpha}{\rightarrow} {}^{206}Pb$$

Health effects of ^{222}Rn decay have been a special concern because these isotopes can cause lung cancer, especially at higher levels of radiation in close area.

Because of the recognized air contamination with ^{222}Rn radioactivity in the Russeifa area, this research proposal is advanced to explore means of better control emission of ^{222}Rn gas from soil to neighbouring community atmosphere. A selected dumpsite employed as a park (Russeifa National Park) was a subject of this study as the area is cultivated to different landscaping and fruit trees. In addition, the Park is irrigated with raw wastewater from a yeast manufacturing factory. The nutrient and organic solutes-rich water has improved soil structure and thus, facilitates investigating assumptions. Here, we hypothesize that filling soil with moisture and/or changing soil pore size distribution using plant species with different root system will decrease the volume of pores through which ^{222}Rn would move and therefore this would retard ^{222}Rn diffusion from soil to the atmosphere.

2. LITERATURE REVIEW:

The ^{238}U natural radioactive series is the major source of natural radiation in the environment. Each ^{238}U nucleus emits an α particle, and thereby an atom of the (^{234}Th) isotope is formed. In the sequence of the following reactions, ^{206}Pb is formed, which is non-radioactive (stable) and therefore stops the sequential reaction. Of particular interest is the portion of the 14-step sequence of ^{238}U radioactive decay series, which involves the formation of gaseous ^{222}Rn, chemically inert but radioactive gas that exists in soil and rocks of all geological environments. The chemical inertness of ^{222}Rn is due to its stable electronic configuration [Xe] $6s^2$-$4f^{14}$-$5d^{10}$-$6p^6$. However, ^{222}Rn is highly radioactive and decays by the emission of energetic α particle to ^{218}Po, and to other solid progeny.

$$^{238}U \xrightarrow{\alpha} {}^{234}Th \xrightarrow{\beta} {}^{234}Pa \xrightarrow{\beta} {}^{234}U \xrightarrow{\alpha} {}^{230}Th \xrightarrow{\alpha} {}^{226}Ra \xrightarrow{\alpha} {}^{222}Rn \xrightarrow{\alpha} {}^{218}Po \xrightarrow{\alpha} {}^{214}Pb \xrightarrow{\beta} {}^{214}Bi \xrightarrow{\beta} {}^{214}Po \xrightarrow{\alpha} {}^{210}Pb \xrightarrow{\beta} {}^{210}Bi \xrightarrow{\beta} {}^{210}Po \xrightarrow{\alpha} {}^{206}Pb$$

Where,

U: uranium,	Th: thorium,	Pa: protactinium,	Ra: radium,	Rn: radon
Po: polonium,	Pb: lead,	Bi: bismuth		

Because of ^{222}Rn inertness, and low solubility in water (Majumdar, 2000), Rn itself doesn't pose much of a danger to human being (Jones, 1999). The alpha emitting progeny of ^{222}Rn are the primary agents with direct impact on human health. Although alpha particles do not penetrate deeply into tissue, ^{222}Rn progeny that have been inhaled into the lungs are in close contact with lung tissue and a substantial radiation dose is deposited by the decay of this progeny. Therefore, exposure to high concentrations of ^{222}Rn gas is known to cause lung cancer in underground ^{238}U

miners (Gomez Escobar, 1999). In addition, chronic exposure to more moderate concentrations of ^{222}Rn in dwellings may be considered as a major cause of lung cancer in the public at large.

Radon-222 enters the atmosphere from earth's surface where it is produced via radioactive decay of ^{226}Ra, which is member of the uranium series (Gaggeler et al., 1995). Because ^{226}Ra is present in mineral grains, when it decays ^{222}Rn must be released from the solid matrix by recoil (the process by which an atom (Rn) recoils in the opposite direction from the path of particle ejection following the radioactive decay of its parent). For a ^{222}Rn atom to escape from the mineral grain into the pore space, the decay must occur within the recoil distance of the grain surface (UNSCEAR, 2000). Thus, only the ^{222}Rn atoms produced in the subsurface layer of the mineral grains have a nonzero probability of escaping the solid matrix (Barillon et al., 2005). The range of recoil distance for ^{222}Rn is 20-70 nm in common minerals, 100 nm in water and 63 μm in air (UNSCEAR, 2000). The fraction of ^{222}Rn atoms released into rock or soil pore space from a ^{226}Ra-bearing grain is called the *emanation coefficient*, the *emanation factor* or the *emanating power* (Gomez Escobar et al., 1999). Typical emanation coefficients for rocks and soils range from 0.05 to 0.7 (UNSCEAR, 2000).

Radon-222 emission to the atmosphere was first observed in and around phosphate ore mines and dumps of phosphate extraction spoils. Studies indicated that underlying phosphate rocks were found to affect the concentration of ^{222}Rn in the overlaying soil strata as well as in the ambient air above the soil surface (Fourati et al., 1988; Lysandrow et al., 2008; Azouzazi, 2001; Saueia et al., 2005; Kullab, 2001).

Migration of ^{222}Rn in geological media can occur by both diffusion and advection. Diffusion is the dominant process for ^{222}Rn migration in most subsurface environments. Because soil air has generally 10^3-10^4 times ^{222}Rn gas concentration than the atmosphere, there is always a concentration gradient maintained by the continuous decay of ^{226}Ra (Sharma et al., 2001). The equation for steady-state, one-dimensional, vertical diffusive transport of ^{222}Rn in soils is

$$D\frac{d^2C}{dz^2} = \lambda C - Q$$

Where D is the effective diffusion coefficient, C is the concentration of ^{222}Rn (activity/volume), λ is the decay constant of ^{222}Rn (2.1×10^{-6} s^{-1}), and Q is the source term for ^{222}Rn (Bq m^{-3} s^{-1}). The source term for Rn in the soil can be estimated by the equation:

$$Q = \frac{R\rho_b \lambda E}{\varphi}$$

Where R is the specific activity of ^{226}Ra in the soil, ρ_b is the dry bulk density of the soil, E is the ^{222}Rn emanation coefficient, and φ is the porosity (Clifford and Stephen, 2006).

The ^{222}Rn emission potential for a given region is likely to be the result of a combination of properties of the underlying rocks, type of soil cover and soil properties, such as distribution of ^{238}U and ^{226}Ra, soil porosity, pore size distribution, moisture content and particle size distribution of soil (Khayrat et al., 2001; Matiullah et al., 2006; Shweikani et al., 1995; Nagarja et al., 2003).

The UNSCER (2000) report showed that soil moisture content plays an important role in the emission of ^{222}Rn from soil, for several reasons. Soil moisture, in the form of a thin film of water surrounding soil grains, directly affects ^{222}Rn

emanation from the solid phase to soil air by capturing the ^{222}Rn recoils. These captures increase the likelihood that ^{222}Rn atoms will remain in the pore space instead of crossing the pores and imbedding themselves in adjacent soil grains. Marc *et al*. (1996), Nguyen *et al*. (2005), Hongbing *et al*. (1995) and Barillion *et al*. (2005) found that increasing soil moisture resulted in increased amounts of ^{222}Rn concentration up to the levels approaching saturated soil, where ^{222}Rn concentrations decreased abruptly, due to a sharp decrease in soil permeability (m^2).

Soil porosity also affects ^{222}Rn emission. Shweikani et al. (1995) showed that the diffusion of ^{222}Rn from soil to atmosphere increased with an increase in porosity of the medium. At low porosity, soil grains are arranged close to each other and, hence, ^{222}Rn atoms in pore space of the subsurface soil find their path to the surface being blocked by other soil grains. This blockage would have been replaced with air if the porosity were increased. It has been reported that the grain size and shape are two important factors that control the emanation of ^{222}Rn in soil. They determine how much ^{226}Ra near the grain surface is high enough to allow significant ^{222}Rn to escape into pore space. Generally, ^{222}Rn emanation is inversely proportional to grain size, particularly ^{222}Rn emission decreases with sand content in the soil and increased with clay content (UNSCER, 2000 and Khayrat, 2001). Shwekani et al. (1995) and Kullab, (2005) suggested that the emanated ^{222}Rn atoms should decrease with increasing grain size as the ratio of grain surface area to its volume gets smaller and this causes a reduction in ^{222}Rn emanation potential.

Singh et al. (2005) reported that concentrations of ^{222}Rn and its progenies (^{218}Po, ^{214}Pb, ^{214}Bi and ^{214}Po) vary from time-to-time, depending upon the meteorological conditions, such as temperature, wind speed, and rainfall. Kullab *et al.* (2001), Kullab (2005) and Al-Shereideh *et al*. (2006) reported that the soil ^{222}Rn

level appeared to be affected by seasonal variation. The authors noticed that in winter soil moisture increased and air-filled pores decreased reducing diffusion of ^{222}Rn gas into the atmosphere. On the contrary, with the advancement of dry weather in spring, soil moisture decreased causing a corresponding increase in air filled pores and subsequently a greater ^{222}Rn diffusion into atmosphere. In summer time and irrespective of decreases in soil moisture and increasing air filled pores, the level of ^{222}Rn emission into the atmosphere decreased due to soil coverage with plant residues which act as surface mulch and, subsequently, reduced soil ventilation. In fall, the soil became very dry after a long dry summer and dehydration of plant root residues increased soil pore space, so the ^{222}Rn flow into the atmosphere increased.

Nagaraja et al. (2003), Magalhaes et al. (2003) found that concentration of ^{222}Rn in the atmosphere was at maximum level during early morning hours, generally between 04:00 and 07:00 am. Emission of ^{222}Rn decreased after sunrise to reach a minimum in afternoon time (12:00-4:00 pm). Heating of the earth surface by solar radiation throughout the day and cooling during the night cause a marked diurnal change in temperature near the surface. As a result, cool air near the ground will accumulate Rn isotopes near the surface during the night, while during the day warm and light air will ascend to higher altitude carrying Rn with (Singh et al., 2005 and UNSCER, 2000).

Because of the recognized air contamination with ^{222}Rn radioactivity, many remediation technologies for phosphate mine dumps were developed to reduce such a contamination. Remediation technologies range from physical modification of soil surface, including covering contaminated soil with compacted soil layer in order to reduce ^{222}Rn emission to atmosphere (Jody et al., 2001) and application of biotechnologies in which U, Th an ^{226}Ra ions are taken up by plant roots with the

subsequent capturing of these element in organic tissues, especially in the aboveground portion of plants. Harvesting and disposal of plant cuttings have shown to be an effective redistribution solution of these elements (Andon et al., 2004 and Susan et al., 2005).

Batarseh et al. (2009) showed that U concentration in phosphate rock samples from two mining sites in Jordan was relatively high compared to corresponding concentrations in Egypt, USA , and other countries (Table 1).

Table 1: Elemental composition (mg kg^{-1}) for selected phosphate rocks from different countries (Batarseh et al., 2009)

country	Cu	Pb	As	Ni	Zn	Cr	Cd	Hg	U
Al-Abyad (Jordan)	15.00	0.38	3.90	13.28	44.09	28.42	2.64	0.15	68.64
Al-Hisa (Jordan)	14.00	0.68	5.80	16.63	57.57	30.77	3.87	0.10	57.80
Morocco	22.00	7.00	13.00	26.00	261.00	225.00	3.00	0.04	82.00
Egypt	—	4.00	—	15.00	121.00	51.00	2.30	0.05	27.00
USA	23.00	12.00	13.00	37.00	204.00	109.00	11.00	0.05	41.00

Because of relative enrichment of local phosphate rock with U, this work was advanced. The objective was to explore means to better control emission of ^{222}Rn gas from soil to atmosphere by increasing soil moisture content and/or changing soil pore size distribution using plant species with different root systems (fibrous root vs. tap root).

3. MATERIALS AND METHOD

3.1. Soil location and selection

Russeifa National Park was established in waste deposition mainly from an old phosphate rock mining site. Because the wastes were dumped randomly, the material is heterogeneous and the site topography is undulated. Because of these characteristics, ^{222}Rn emission from soil was expected to vary spatially. To ensure that the study soil sample will be collected from a highly radioactive material, thirteen locations distributed all over the Park were tested in the field for ^{222}Rn.

3.1.1. Measurement of radon radioactivity

Radon-222 radioactivity was detected using an integrated passive radon dosimeter cup Figure (1). The cup is made of plastic and a 1.5×1.5 cm^2 CR-39 paper is mounted on its bottom. The CR-39 paper is 0.5 mm thickness and made of allyl diglycol polycarbonate produced by Pershore Moulding Limited, England. This material serves as a solid state nuclear track detector (SSNTD) (Espinosa et al., 1992).

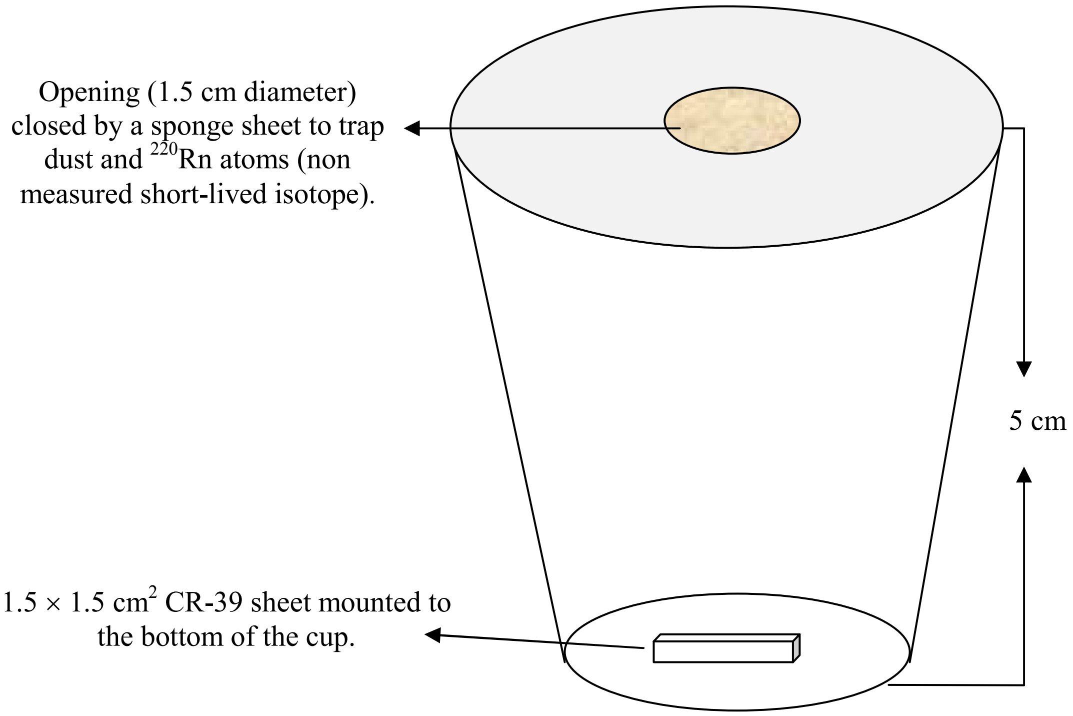


Figure 1: The CR-39 dosimeter cup.

Field ^{222}Rn radioactivity was determined by making soil pores large enough to accommodate the dosimeter cup (50 cm depth and 10 cm diameter). For each of the selected thirteen locations in the Russeifa National Park, a PVC tube of the same hole dimensions was first placed in each hole then an upside-down dosimeter cup was placed inside each tube (Photo 1) and the surrounding tube was refilled with soil. The dosimeter cups were left in the site for approximately three weeks—long enough for the ^{222}Rn to reach equilibrium with ^{226}Ra. We assumed that the three week period was also long enough for a significant number of α-hits on the CR-39 paper as a result of the decay of ^{222}Rn (Kullab, 2005; Abumurad et al., 2001; Al-Shereideh et al., 2006).

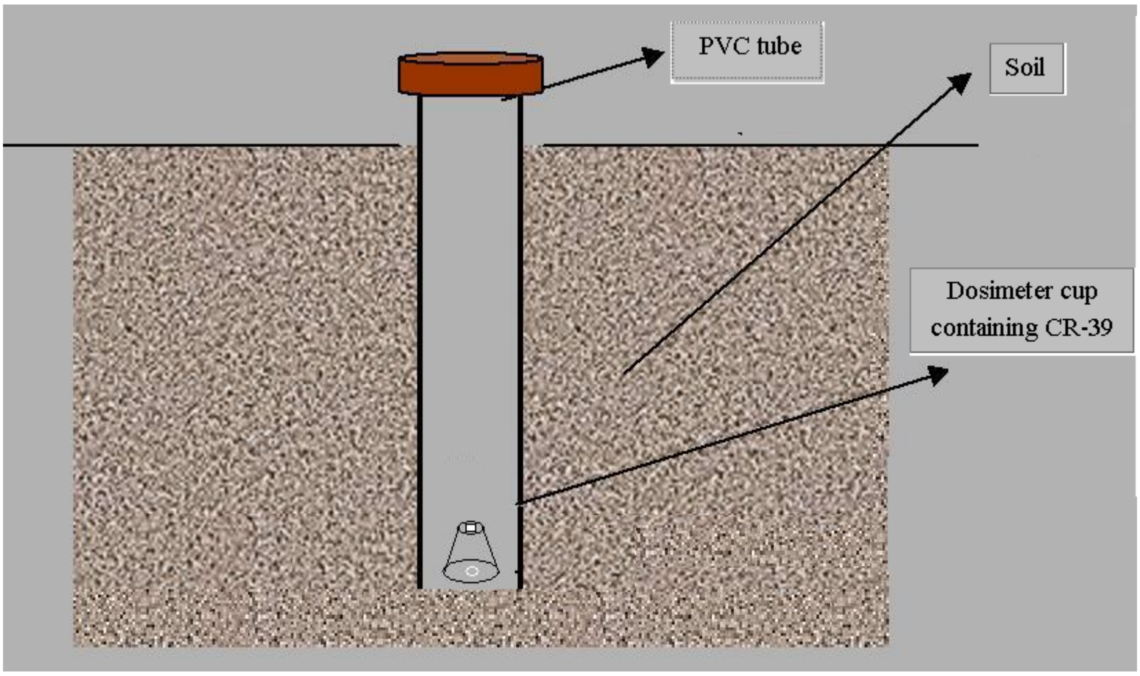




Photo 1: A field photo showing placement of CR-39 cup in soil

The CR-39 papers were then retrieved and chemically etched in the laboratory by submerging for 9 hours in 7*M* KOH solution maintained at 70^{o}C. After etching, the papers were washed with distilled water, left to dry, and stored at freezing temperature (Kullab, 2005; Abumurad *et al.,* 2001; Shereideh *et al*., 2006).

The number of α-hits on each CR-39 paper was counted using a microscope at 100X magnification. The counted hits for each CR-39 paper transformed into concentration (C) in units of k Bq m^{-3} using Rasas et al. (2005) equation.

$$C = \frac{C_o t_o \rho}{\rho_o t}$$

where C_o is the ^{222}Rn radioactivity of the calibration chamber (90 kBq m^{-3}), t_o is the calibration exposure time (48 hours), ρ_o is the number of α-hits per unit area of the calibrated CR-39 paper (3.309×10^4 hits cm^{-2}), t is the exposure time of the distributed dosimeter cups in hours and ρ is the number of α-hits per unit area of the CR-39 papers. The variable ρ is calculated by the following formula:

$$\rho = \frac{\overline{X}}{A}$$

where $\overline{X}$ is the average number of hits for about 30 microscope fields and A is the area of the microscope field at 100X magnification (0.002973 cm^2) (Al-Bataina et al., 1997).

3.2 Experimental design and treatment:

The experiment was carried out using repeated measure design with five replicates. The repeated measure design was thought to be the most suitable design to this research. The design comprised five main plots--four plant plots and one uncultivated blank plots. These plots were used to separate the effect of cultivation on ^{222}Rn emission from that of changing soil moisture only.

3.2.1 Plant treatments:

A composite surface soil sample (0-20 cm) from the site that showed the highest ^{222}Rn emission was collected from the Russeifa National Park and brought to the laboratory. A subsample of this composite sample was subjected to traditional soil chemical (Page et al., 1982) and physical analysis (Gee and Bauder (1986). The sample was air dried, gently ground to pass 2 mm sieve and stored for later use. Subsamples, 16 kg each, were packed in plastic pots (24.5 cm diameter × 26 cm height) at ρb 1.3 g cm^{-3}. The pots were planted with four plant species selected--alfalfa, pepper, and eggplant with tap root systems and barley with a fibrous root system. For barley and alfalfa, 10 seeds from each plant were planted in each pot. For eggplant and pepper, two seedlings of each were transplanted into the respective pots.

3.2.2 Water treatment:

To guide irrigation for each treatmental plot, a computer guided tensiometer (Stevens POGO Soil Sensor Instrument) was inserted in each fifth treatmental pot, including plant treatment (Photo 2). This device was used to indicate soil moisture tension between 0.3 bar (field capacity) and 0.5 bar. and thus to help calculate the required volume of irrigation water that should be applied to each pot to compensate for moisture loss between these two soil moisture tension tensions as calculated by the following equation (Keller and Bliesner,2000):

$$(\theta v_{F.C} - \theta v_{measured}) \times Vs$$

where:

$\theta v_{F.C}$ = volumetric water content at field capacity ($cm^3\ cm^{-3}$);

θv_m= measured volumetric water content ($cm^3\ cm^{-3}$); and

Vs = volume of soil (cm^3).



Photo2: A photograph showing the Stevens POGO Soil Sensor device.

3.2.3 Calibration of Stevens POGO Soil Sensor:

Since ^{222}Rn emission from soil depends largely on volumetric soil moisture content, this parameter has to be continuously monitored along with ^{222}Rn emission from soil. Traditional determination of θv requires soil sampling and, thus, results in soil disturbance i.e. termination of the experiment at the point of soil sampling. Subsequently, nondestructive soil moisture determination was sought. The Stevens POGO Soil Sensor was found to be a good alternative.

Figure (2) shows the relationship between Stevens POGO θ_v% and the corresponding volumetric soil moisture (θ_v%) which was calculated from the determined gravimetric soil moisture content (θ_w) using the following relation:

$\boldsymbol{\theta_v} = (\boldsymbol{\theta_w} \times \boldsymbol{\rho_b})$, Here we assume density of water 1g cm^{-3}.

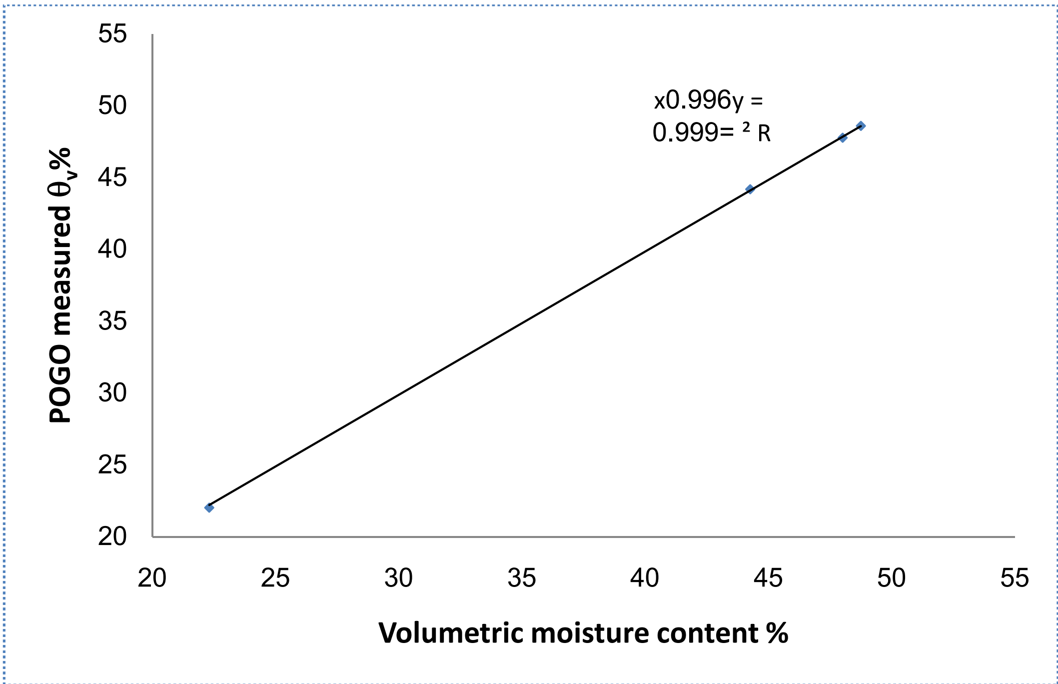


Figure 2: Relation between Stevens POGO (θ_v%) and the volumetrically determined θ_v%

The Figure shows that the relation was linear with high degree of correlation coefficient. Therefore, the Stevens POGO Soil Sensor was used for all subsequent determinations of volumetric soil moisture.

3.2.4. Measurements of ^{222}Rn emission from treatment soils

To ensure that emitted Rn from each pot was confined into the ambient air, each pot was placed inside a frame of wood (1×1 ×1 m^3) covered by a transparent plastic sheet (Figure 3). The whole experimental setup was placed inside a greenhouse to provide optimal growing conditions.

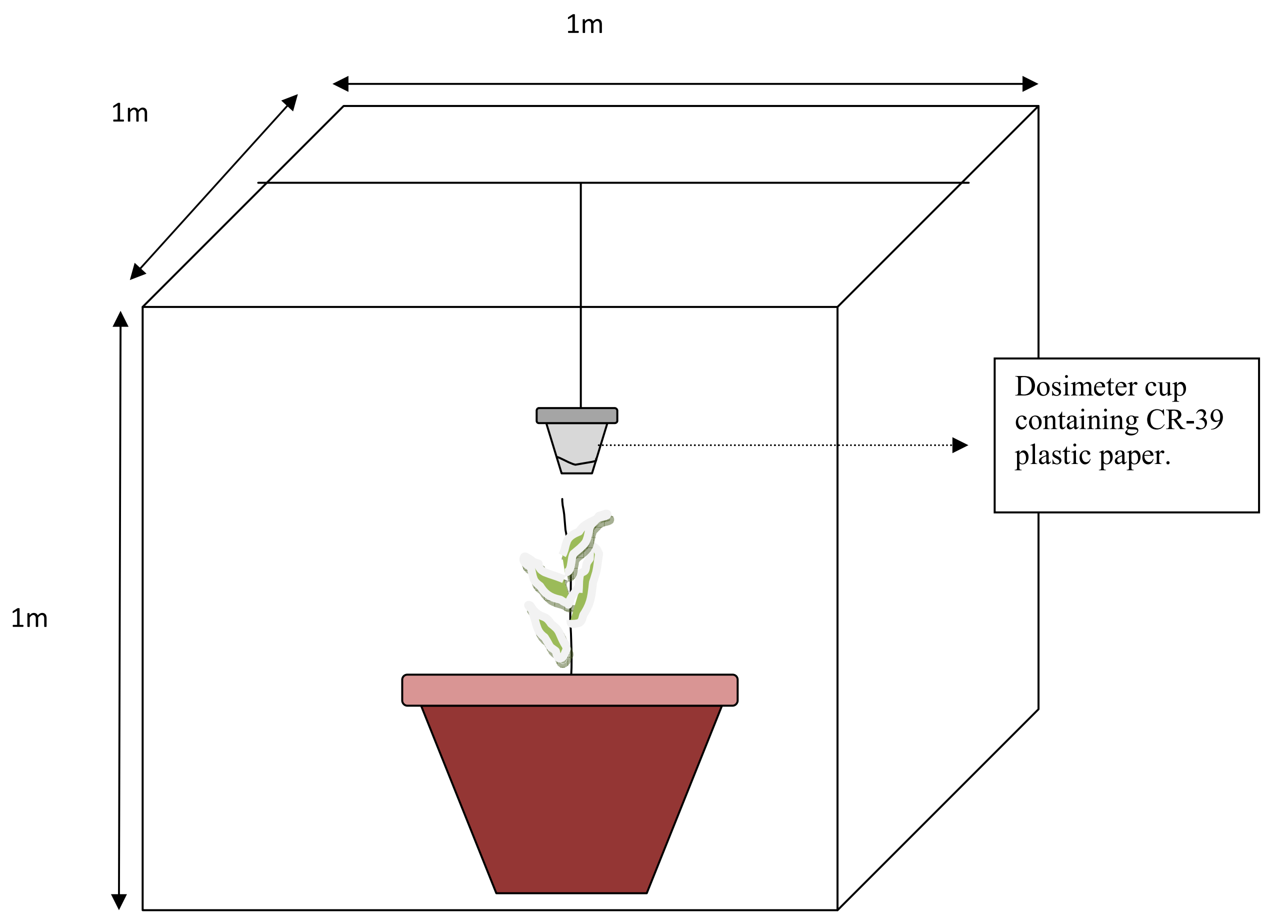


Figure 3: **Experimental setup**

Emission of "α" particles from ^{222}Rn was measured every week using the dosimeter cups to which CR-39 papers were attached. The dosimeter cups were annexed from the roof of the plastic box to avoid any shadowing by growing plant canopy.

Following each α-particle measurement, the plastic sheet was removed off each box to facilitate renewal of ambient air of fresh one. The CR-39 papers which were subjected to α-hits from each pot were chemically treated as previously described and numbers of α-hits were counted accordingly.

3.2.5. Root parameter:

Because soil pore distribution, and thus rate of ^{222}Rn emission from soil, is expected to be affected by root type and growth, root length at the end of the experiment was determined. Soil in each pot was washed with tap water and the leachate was forced to percolate over a fine sieve. The roots were extensively cleaned from soil particles, placed in plastic bags and stored in refrigerator until further measurements. Root length density was determined by immersing the entire root system in water for separation of root parts from each other then the disentangled roots were spread over a scanner tray for digitizing with an image acquisition device (WinRHIZO) using a desktop optical scanner Photo (3). The WinRHIZO program was used to calculate root length density in (cm cm^{-3}), and specific root length (cm g^{-1}) after which the scan samples were again placed in a paper bag and dried at 70 ^{o}C for 48 hours for estimation of root dry mass (Talhouni, 2009).



Photo 3: Desktop optical scanner

3.3. Adjustment of soil water content

The effect of soil moisture content on ^{222}Rn emission from soil was also studied. A triplicate soil subsamples, 1 kg, were packed into plastic containers (10 cm diameter × 50 cm height), water was added to each soil subsamples to reach gravimetric moisture content of 0%, 5%, 10%, 15%, 20%, 25% and 30% the former values corresponded to respective volumetric moisture content (as percent of total porosity) of (6.5%, 13%, 20%, 26%, 33% and 39%). Radon-222 emission was measured using the dosimeter cups to each CR-39 paper which was attached at 25 cm above the soil surface The surface of each container was covered with a plastic sheet to prevent escape of α-particles. Each setup was left standing for 21 days after which the CR-39 detectors were removed and chemically treated as previously described and numbers of α-hits were counted accordingly.

Having determined the ^{222}Rn concentration, the exhalation rate from each sample was calculated using the following equations (Rahman et al., 2008):

$$F = F_O - \omega C(t)$$

where F is the back diffusion corrected exhalation rate (Bq m^{-2} h^{-1}), $\omega = \varepsilon\lambda Z_O$ is known as the back diffusion constant for a given material (m h^{-1}), ε is the total porosity, and C(t) is the ^{222}Rn concentration which has to be exhaled from the surface of the sample to void the space of the chamber (Bq m^{-3}). Fo is the uncorrected exhalation rate (Bq m^{-2} h^{-1}) and its calculated using the following equation:

$$F_O = \frac{C(t)[\omega A+\lambda V]}{A\left[1-e^{-(\omega A/V+\lambda)t}\right]}$$

Where A is the surface area of the sample (m^2), V is the volume of the void space in the closed chamber (m^3), t is the ^{222}Rn accumulation time in a closed chamber (h), and and λ is the ^{222}Rn decay constant (h^{-1}).

3.4. Determination of soil pore size distribution:

The effect of pore size on radon exhalation rate from soil was studied. The soil pore size distribution was derived from soil moisture characteristic curve (SMCC) which was estimated using the ceramic plate apparatus method described by Gee and Bauder (1986) (Figure 4 and 5) shows the SMCC and soil pore size distribution, respectively.

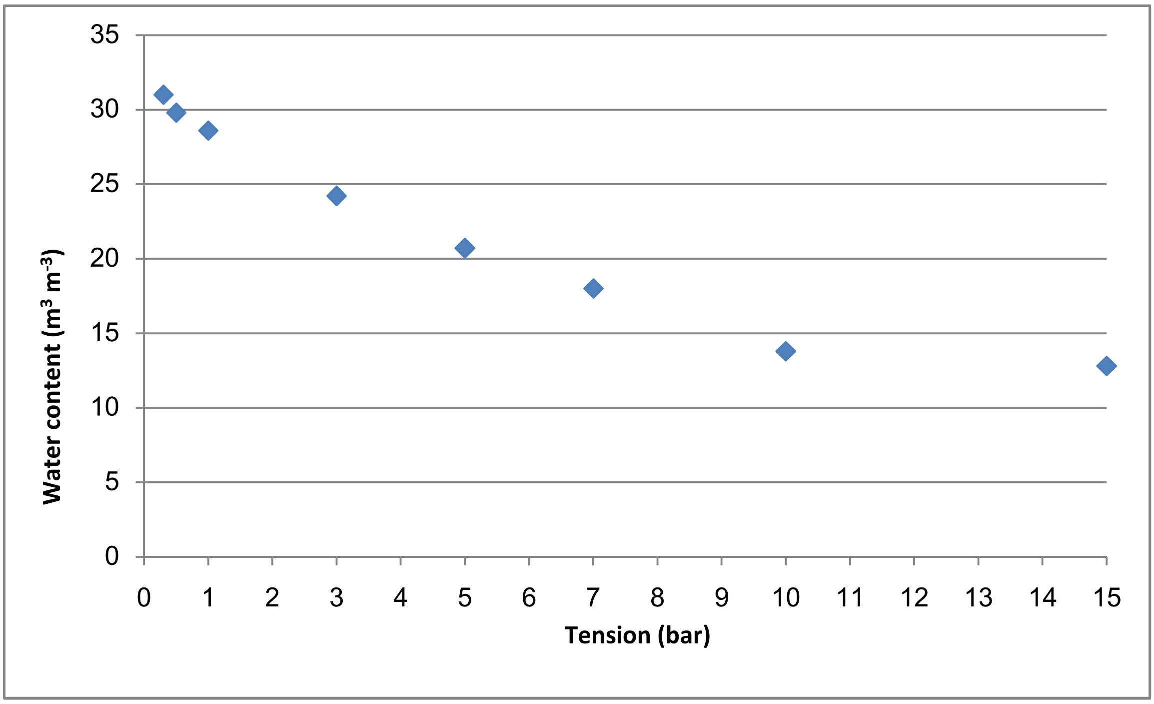


Figure 4: Soil moisture characteristic curve

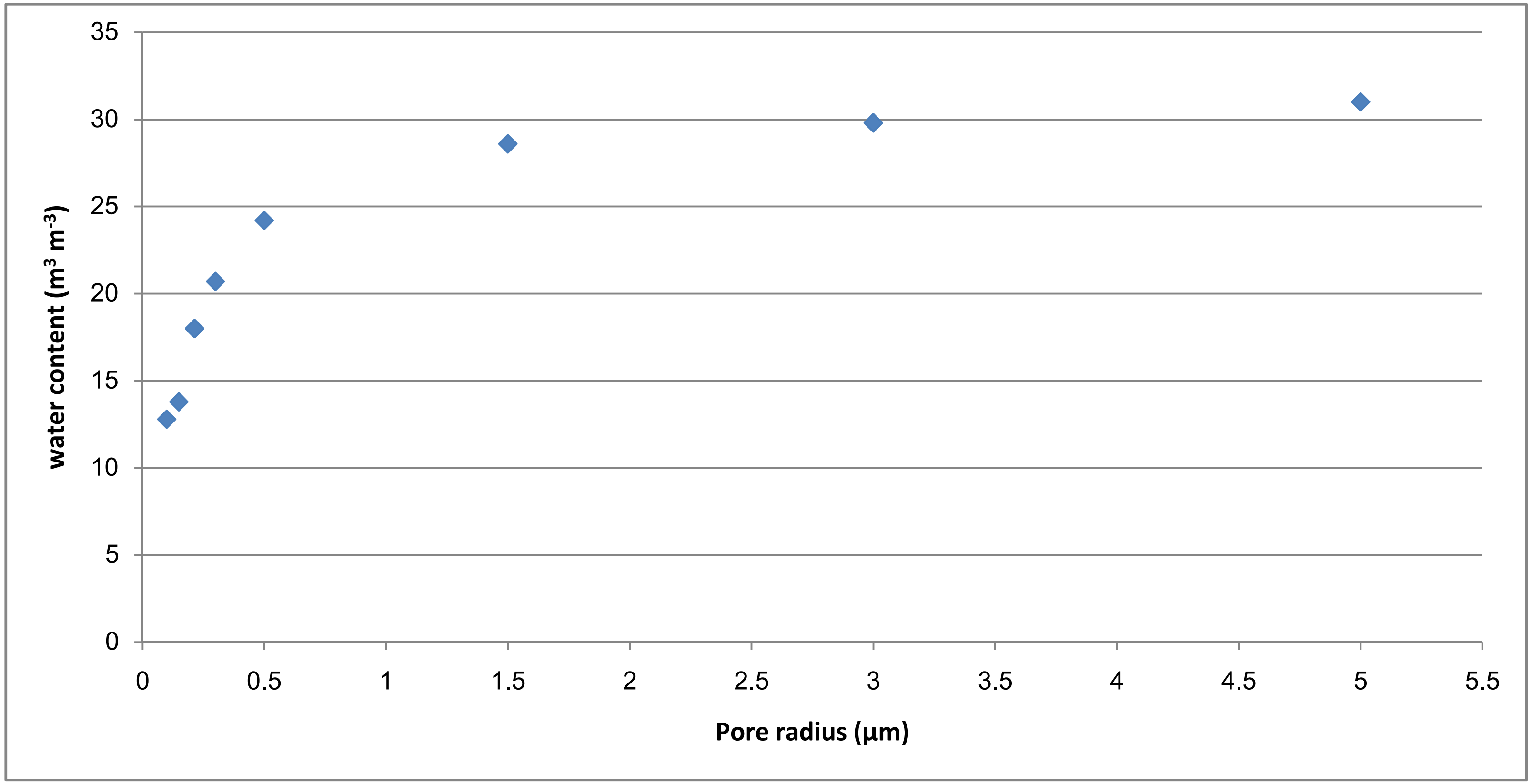


Figure 5: Soil pore size distribution.

4. RESULTS AND DISCUSSION

4.1 Field investigation:

Values of ^{222}Rn radioactivity in soil for the ten locations in the Russeifa National Park and similar values for the other three sites (9, 11 and 13) representing the phosphate extraction waste dump site near the park are presented in Table (2).

Table 2: The ^{222}Rn radioactivity concentration (kBq m^{-3}) in soil as measured by CR-39 dosimeter cup.

Sample No.	Average Number of Tracks*	Track Density (hits cm^{-2})	Radon Radioactivity (kBq m^{-3})
1	735.30 ± 63.69	247225	67.00
2	60.47± 8.909	20182	5.50
3	588.59± 56.49	198116	53.70
4	517.00± 41.95	173898	47.20
5	566.50± 38.99	190716	51.80
6	685.41± 28.42	230407	62.60
7	755.17± 37.03	253952	69.10
8	729.29± 21.80	245207	66.60
9	780.89± 38.53	262698	71.20
10	700.53± 58.56	235789	64.00
11	854.1± 48.94	287252	78.10
12	580.07± 37.91	195089	53.00
13	919.63± 47.87	309452	84.10

*Average of 30 microscope field counts.

Of the thirteen sites that were sampled in this study, the phosphate extraction waste dump site appeared to have the highest radioactivity of ^{222}Rn (> 780.89 kBq^{-3}). This is expected, because this site was constructed on an old phosphate mine and this area form a large hills of phosphate slag material contain a high concentration

of natural radioactive ^{238}U (523.2 Bq kg^{-1}) which is responsible for elevated ^{222}Rn concentration (Al-Jundi, 2002; Al-Jundi et al., 2008). For the other sites, located within the Russeifa National Park boundary, radioactivity levels ranged between 5.50 and 69.10 $kBqm^{-3}$. This relatively low radioactivity in comparison to that in the phosphate extraction waste dump site can be explained by the fact that the surface soil of the Russeifa National Park sites were imported from outside areas not known to be enriched by phosphate ore. Such a soil dilution caused a reduction in ^{222}Rn of these samples.

Based on the above results, soil number 13 was selected for this study. A composite surface soil sample (0-20 cm) from the site was collected and brought to the laboratory. The sample was air dried, gently ground to pass 2 mm sieve and stored for later use.

4.2 Soil analysis:

A subsample of the collected composite surface soil sample from site number 13 from the phosphate extraction waste dump site was subjected to major physical analyses. Tables (3) summarize results of the soil physical properties.

Table 3: Selected physical properties of the soil sample.

Property	Value
Sand%	62
Silt%	14.3
Clay%	23.7
Textural class	Sandy clay loam
Bulk density (gcm^{-3})	1.29
Porosity%	52

4.3 Changes in soil moisture content:

Figure (6) shows that measured soil moisture during the growing season of each crop changed little with time. This may be due to the prevailing cold and humid weather throughout the growing period of all tested plants (13/12/2009 – 21/2/2010).

As a result, any changes in ^{222}Rn emission from soil can be attributed to the effect of changing soil porosity due to the growing plant roots.

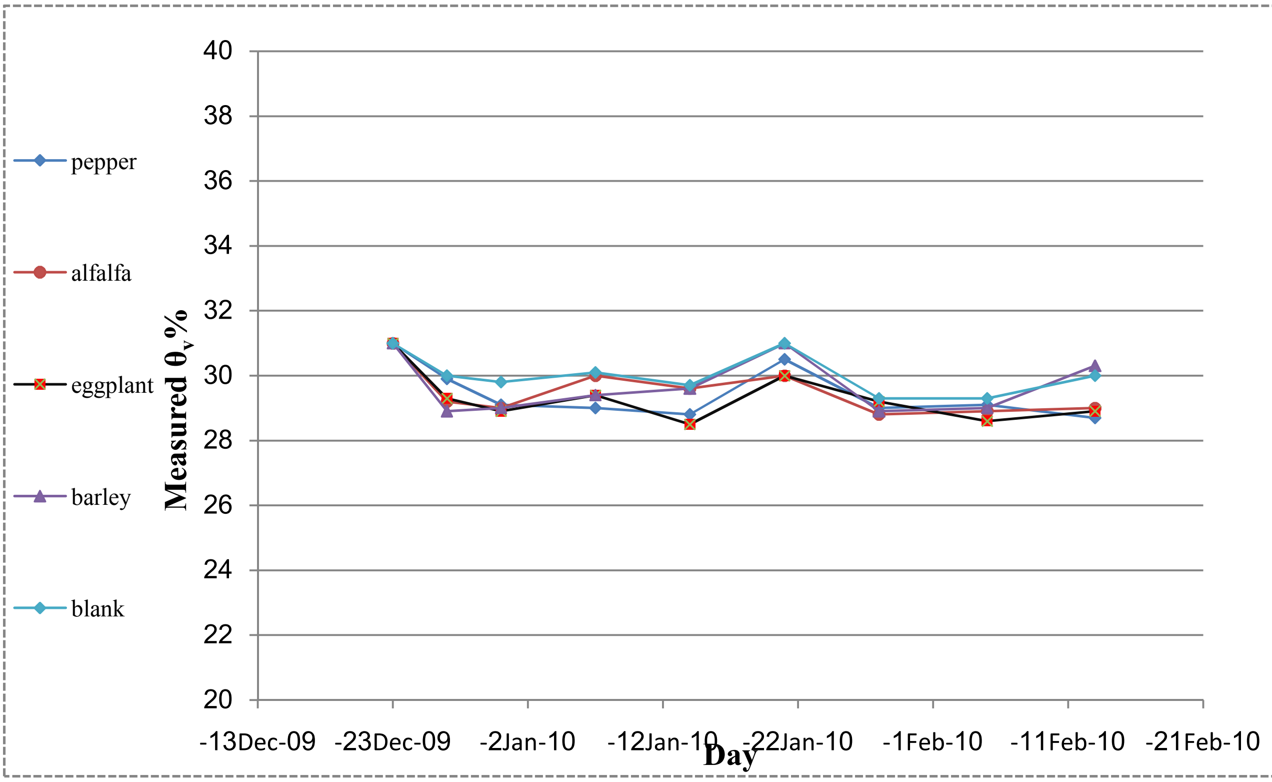


Figure 6: Changes in soil moisture content during the growing season

4.4. Effect of soil moisture content on ^{222}Rn emission from soil

Results of ^{222}Rn emission from soil samples with increasing gravimetric moisture content are presented in Table (4). These data are also presented in Figure (7).

Table 4: Radon-222 emission (Bq m^{-3}) from soil samples with different moisture content.

Soil moisture%		Radon radioactivity (Bq m^{-3})	Radon exhalation rate (Bq m^{-2} hr^{-1})
Gravimetric %	%Porosity		
0	0	633.33	15.79
5	6.5	763.33	19.04
10	13	888.67	22.17
15	20	952.67	23.76
20	26	1083.33	27.032
25	33	957.50	23.89
30	39	940.00	23.45

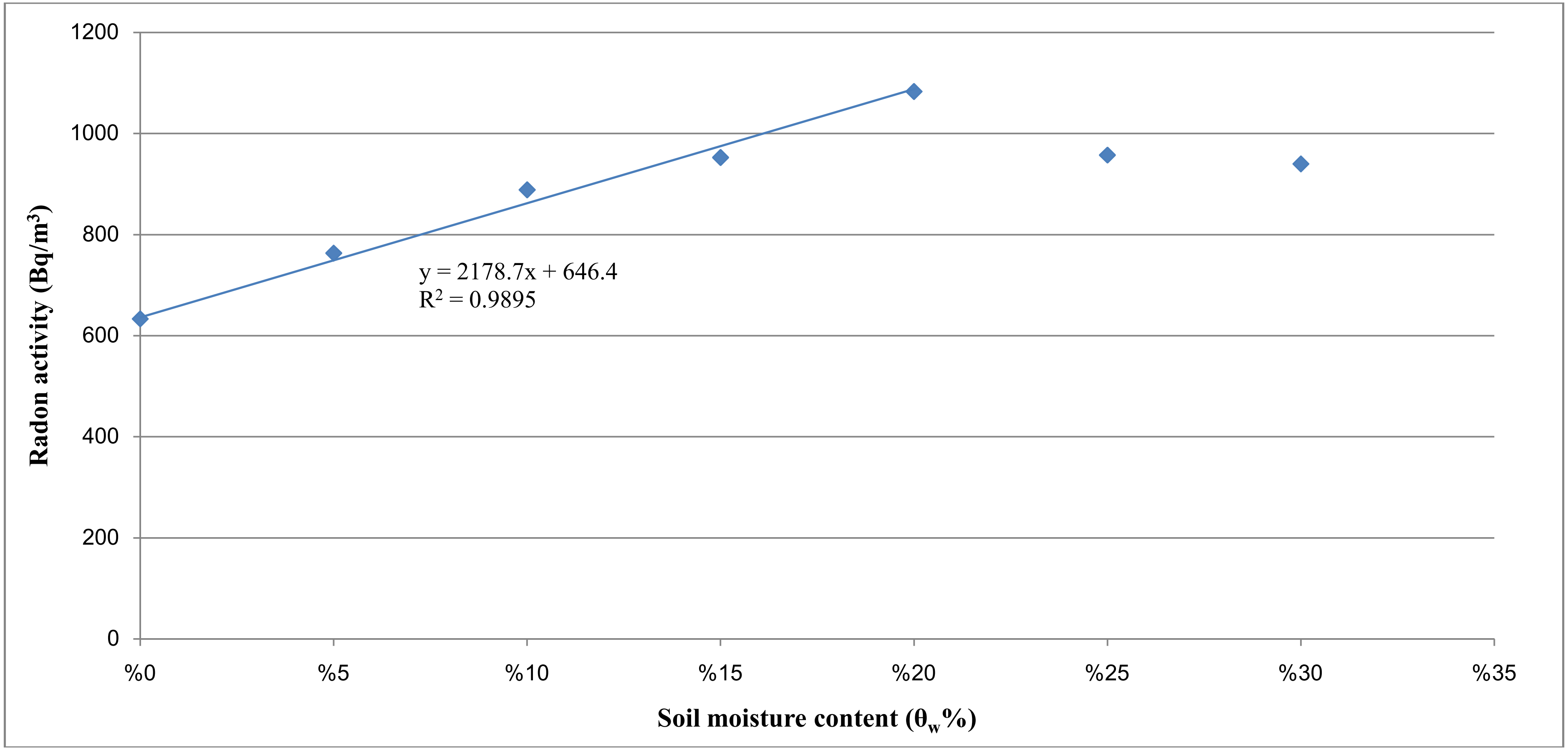


Figure 7: Effect of soil moisture on radioactivity of emitted ^{222}Rn

Figure 7 shows that radioactivity of emitted ^{222}Rn increased linearly with increasing gravimetric soil moisture content up to 20% (26% 0f total porosity) beyond which radioactivity remain almost at constant value (940 Bq m^{-3} air) provided that dry soil aggregate were homogeneous of almost fine sizes, the resulting porosity of the packed soil pots would be made of medium to fine pore spaces. Therefore, the resulting volumetric soil moisture content equivalent to threshold value of about ≈ 26% total porosity would be the limit at which probability of recoiled ^{222}Rn encounters liquid water reached a maximum value. Nguyen et al. (2005) suggested that when soil was dry, a certain part of ^{222}Rn atoms that escaped from soil solid grains would acquire kinetic energy high enough to enable these atoms to absorb to another solid grain (Figure 8). Such extra energy was thought to originate from the recoil energy, which is the excess Kinetic energy that ^{222}Rn gained due to the conservation of energy and momentum in the decay process of its parent (^{226}Ra). Because the transport distance of highly kinetic ^{222}Rn atoms due to this recoil process is considerably small when atoms move in water (0.1 µm) as compared to their transportation in air (63µm), the probability of some ^{222}Rn atoms adsorbing to the solid phase will decrease rapidly with increasing soil moisture content up to a certain level beyond which ^{222}Rn adsorption wouldn't be affected. Emission of ^{222}Rn from soil, subsequently, will inversely be affected by increasing soil moisture because as content increases above field capacity (≈ 32%), the large pores begin to fill with water and the reduction in air permeability is large (Nazaroff et al., 1988). Figure (7) shows that increasing gravimetric water contents beyond 20% had no effect on magnitude of ^{222}Rn emission from soil. A similar trend was observed by Breitner et al. (2010). In this regard, any ^{222}Rn atom is considered emanated when present either in air- or water- filled pore space. The increase in

moisture content is expected to result in corresponding increase in ^{222}Rn content in the water filled pore space leading to an increase in ^{222}Rn emanation to atmosphere. A maximum emanation is reached when all radon atoms escaping the grain are prevented (by the presence of moisture) from entering other grains.

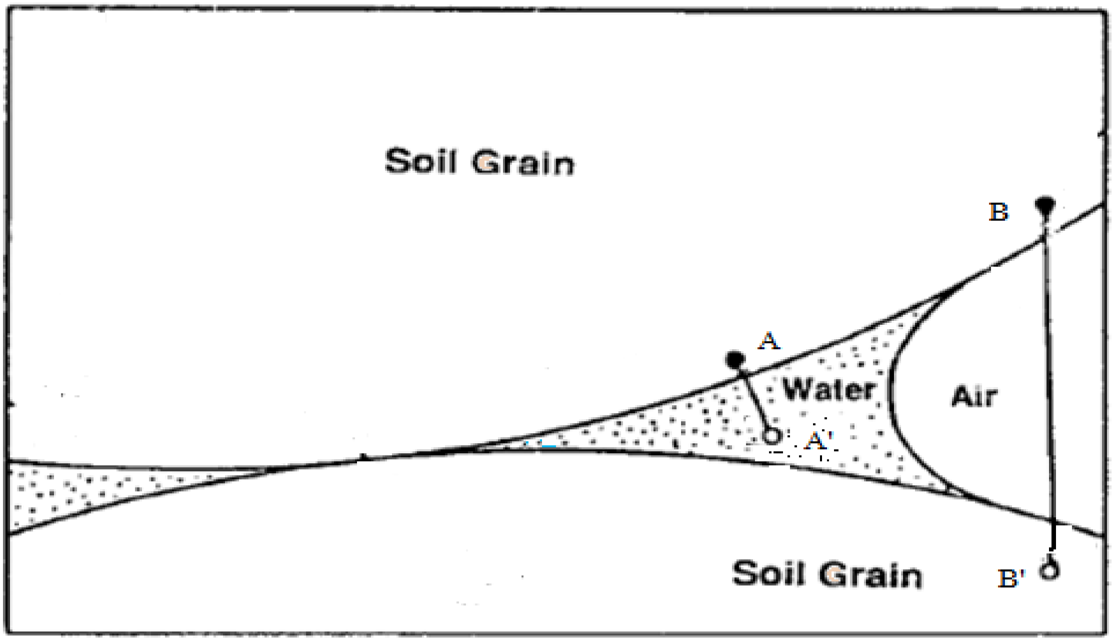


Figure 8: Recoil effects in soil grains, showing differences when water vs. air is present: A = recoil into water, leaving Rn in pore space, B=recoil into air, leaving Rn absorbed in adjacent grain.

4.5. Effect of pore size distribution on ^{222}Rn emission from soil:

Figure 9 shows the relationship between ^{222}Rn diffusion rates (Bq m^{-2} hr^{-1}) from soil samples and pore size.

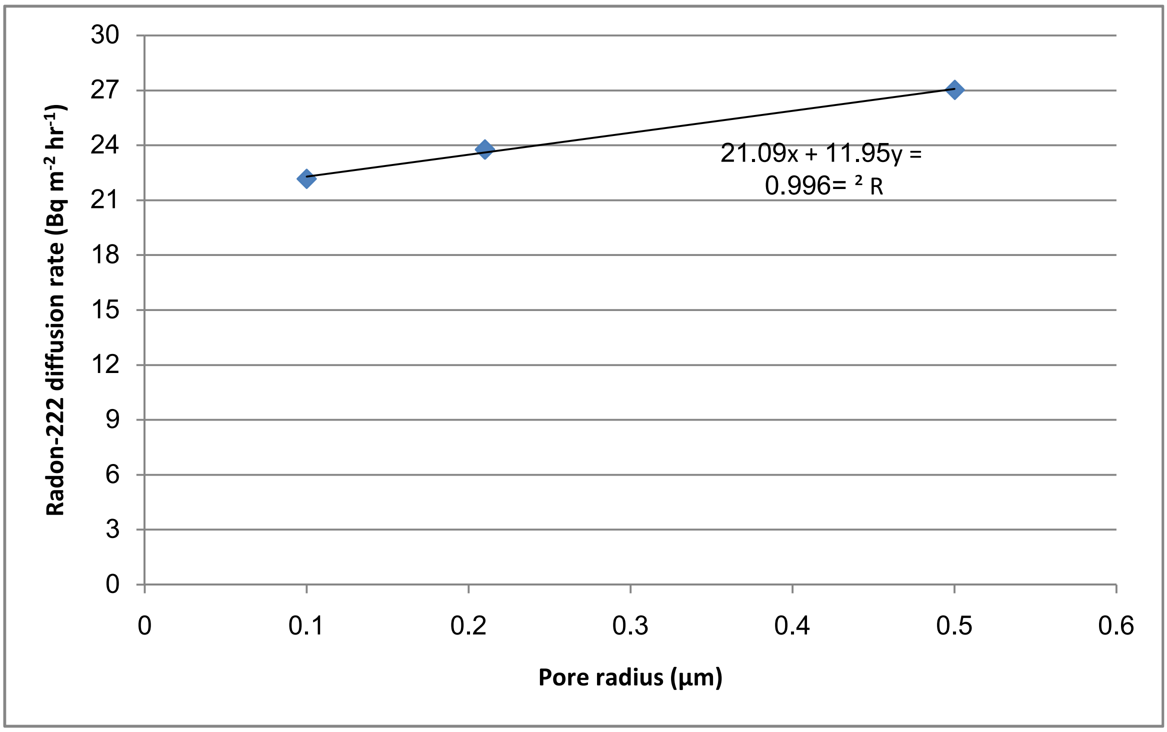


Figure 9: Relationship between ^{222}Rn exhalation rate (Bq m^{-2} hr^{-1}) and pore size.

Figure 9 shows that ^{222}Rn exhalation rate decrease with decreasing the pore radius. This could be because the decreasing in soil permeability (k). Since the soil permeability is based on the microscopic characteristic of the soil: the size, shape, number and orientation of the pore. For example, the soil with large pore can have permeability much greater than a soil with narrow pore. The following equation expresses the soil permeability (Nazaroff et al., 1988):

$$k = \frac{c\varepsilon^3}{TS^2}$$

where k is the permeability (m^2), c is a constant which determined by shape, and size of pore, ε is the porosity, T is the tortuosity (an empirical factor greater than or equal to 1.0 that accounts for the fact that the flow channels are not straight), and S is the specific surface area:

$$S = \frac{6(1-\varepsilon)}{d}$$

where d is the particle diameter.

4.6. Effect of plant roots on ^{222}Rn emission from soil:

4.5.1. Radon emission from soil cultivated to plants with different root systems:

Table (5) shows average radioactivity values of emitted ^{222}Rn (Bq m^{-3}) from soil pots cultivated to the four crops. The data are graphically presented in Figure (10).

Table 5: Radon-222 emission (Bq m^{-3}) from pots cultivated to four crops. Measurements were carried out on weekly basis.

Week	Radon-222 emission (Bq m^{-3})				
	Control	Barley	Alfalfa	Eggplant	Pepper
3	248± 5.92	235.25 ± 2.06	218.75 ± 3.10	170.50 ± 4.80	155.00 ± 5.35
4	260± 3.86	204.50 ± 3.32	195.75 ± 2.99	164.75 ± 8.62	149.25 ± 17.44
5	258± 4.72	181.75 ± 3.59	170.00 ± 1.83	159.50 ± 8.70	143.00 ± 3.56
6	245± 4.90	197.00 ± 4.97	183.25 ± 3.59	149.50 ± 3.70	112.50 ± 4.80
7	240± 2.22	207.00 ± 2.45	177.25 ± 1.89	135.00 ± 6.78	120.75 ± 2.99
8	250± 2.48	210.00 ± 2.16	178.50 ± 2.65	155.00 ± 6.68	129.00 ± 8.04
9	250± 1.83	190.00 ± 1.41	162.50 ± 4.93	153.75 ± 0.96	80.25 ± 4.19
10	255± 2.57	143.51 ± 2.11	129.99 ± 3.31	119.00 ± 3.10	74.00 ± 0.82

Figure (10) shows that all crop-cultivated pots produced ^{222}Rn radioactivity lower than that produced from the control pots (pots left without growing crop but received amounts of irrigation water identical to respective crop pots). Because soil moisture for all treatments didn't change with time (due to high relative humidity inside each box), the impact of soil moisture on ^{222}Rn emission from soil was neglected. In addition, the four control pots were treated as if they were controls for all pot treatments and average values for successive radioactivity measurements were reported in Table (5). Such a reduction in ^{222}Rn emission is a direct result of growing plant roots, which took place in soil pores. Moreover, the growing of plant root in

existing soil pores or through the soil matrix will create compressive and shear stress which can reach 2MPa these pressure which exerted by the growing root will compress the soil in their vicinity and decrease the soil porosity and pore size (Denis *et al*., 1998; Risely *et al*., 2005). This process is expected to cause a corresponding reduction in ^{222}Rn emission from soil to ambient air. This can be explained as; when soil porosity decreases the soil grins are closed to each other. Hence ^{222}Rn atoms in the pore space beneath the surface find their path to the atmosphere was closed with adjacent grain consequently a diminution in ^{222}Rn emission from soil to atmosphere (Nabil *et al*., 2009).

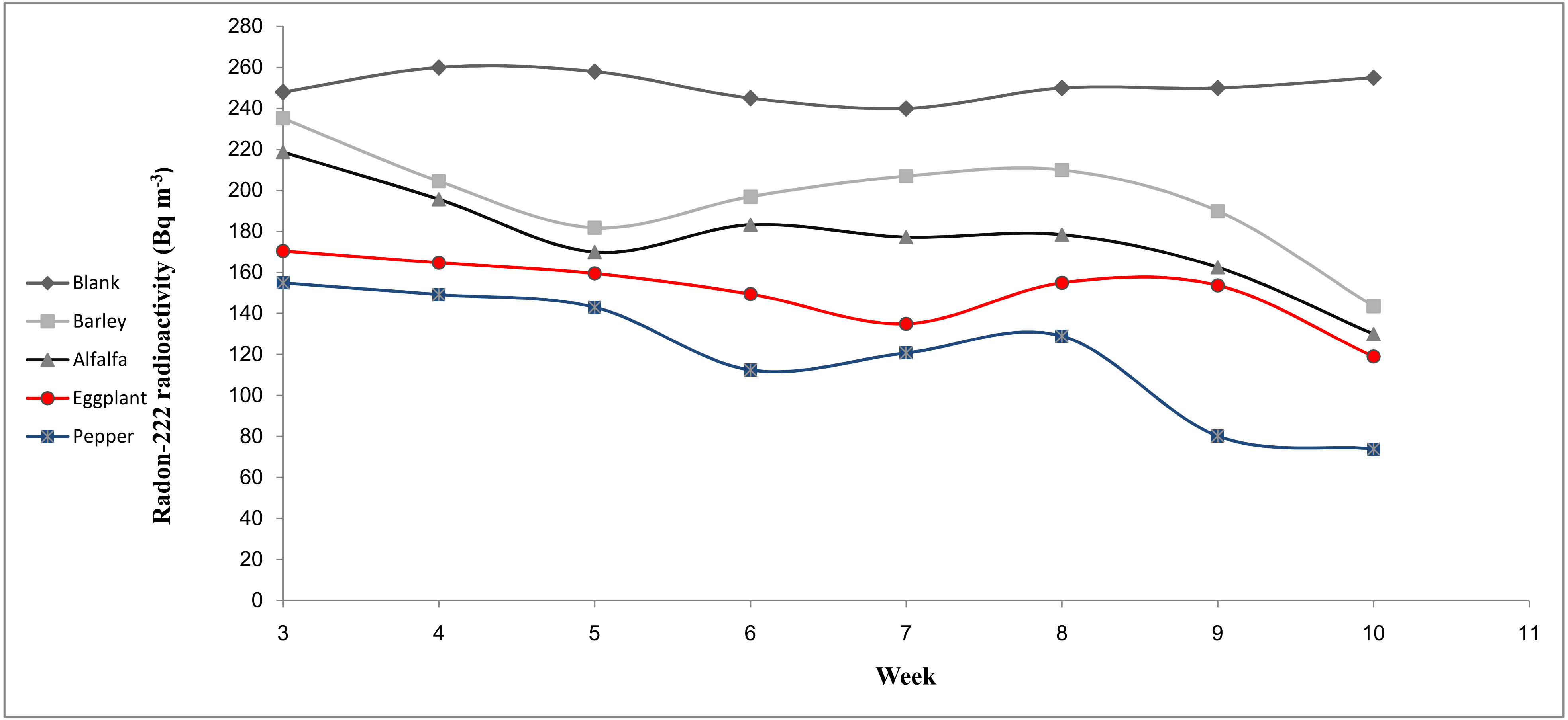


Figure 10: Variations of ^{222}Rn emission from soil under different plant types

As for differences among crops, ^{222}Rn emission from soil cultivated to pepper had the lowest level. Because root growth should fill and compact pores, we expected that ^{222}Rn emission from soil would decrease with increasing root length density (RLD). Data on crop root length density are presented in Table (6).

Table 6: Root length density (cm cm^{-3} soil) of the growing crops at the end of the experiment (8 weeks).

Crop	Total length (cm)	Root length density (cm cm^{-3} soil)
Barley	7417	0.61
Alfalfa	7186.2	0.59
Eggplant	5860.67	0.48
Pepper	3122.95	0.25

The results show that pepper RLD was almost half the corresponding values of other crops. However, pepper root was characterized of being dominated by branches of wide diameter. These were best expressed by specific root length (SRL). As SRL is the root length per unit mass, one would expect SRL to decrease with increasing root mass. Increasing mass should be a result of increasing root volume i.e. root diameter. Subsequently, decreasing SRL had to substantially reduce pore space and macropores (Ostonen et al., 2007). Both would have negative impact on ^{222}Rn emission from soil.

Table (7) shows that pepper has the lowest value of SRL which mean that pepper has the largest root diameter. This finding explains the remarkable impact of pepper root on reducing ^{222}Rn emission from soil. Table (7) also shows that the next to pepper was eggplant; a crop of the same family. Figure (8) shows the relationship between SRL and ^{222}Rn emission from soil.

Table 7: Specific root length density (cm g^{-1}) of the growing crops at the end of the experiment (8 weeks).

Crop	Total length (cm)	Weight (g)	SRL (cm g^{-1})	^{222}Rn emission from high to low
Barley	7417	0.97	7646	1
Alfalfa	7186	1.00	7186	2
Eggplant	5861	0.85	6895	3
Pepper	3122	0.50	6244	4

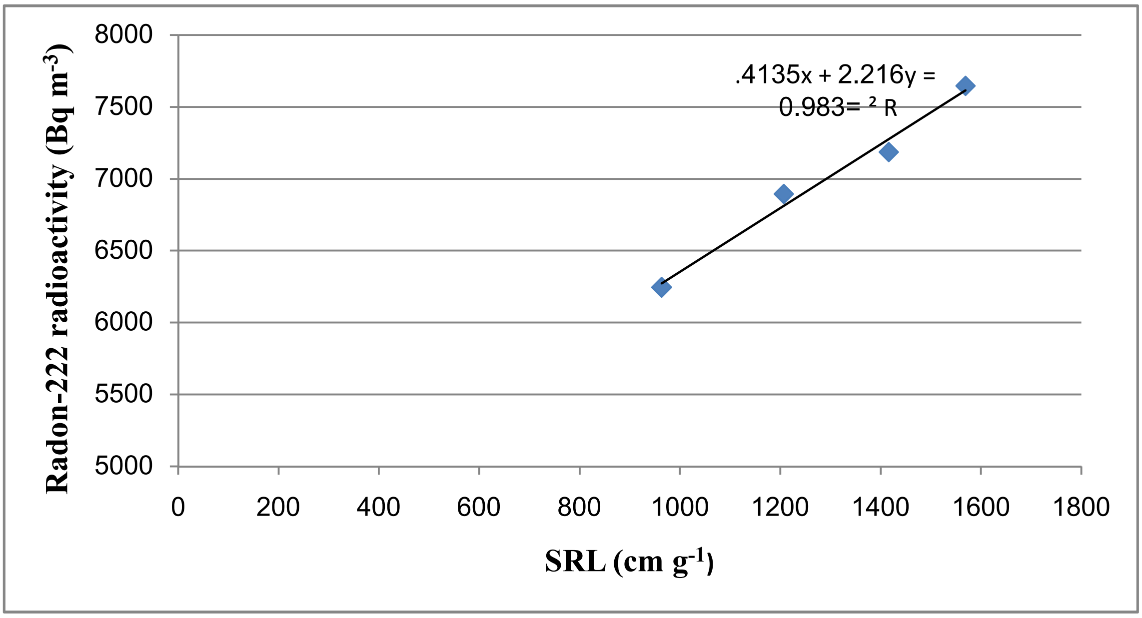


Figure (11) Relationship between SRL (cm g^{-1}) and ^{222}Rn radioactivity (Bq m^{-3})

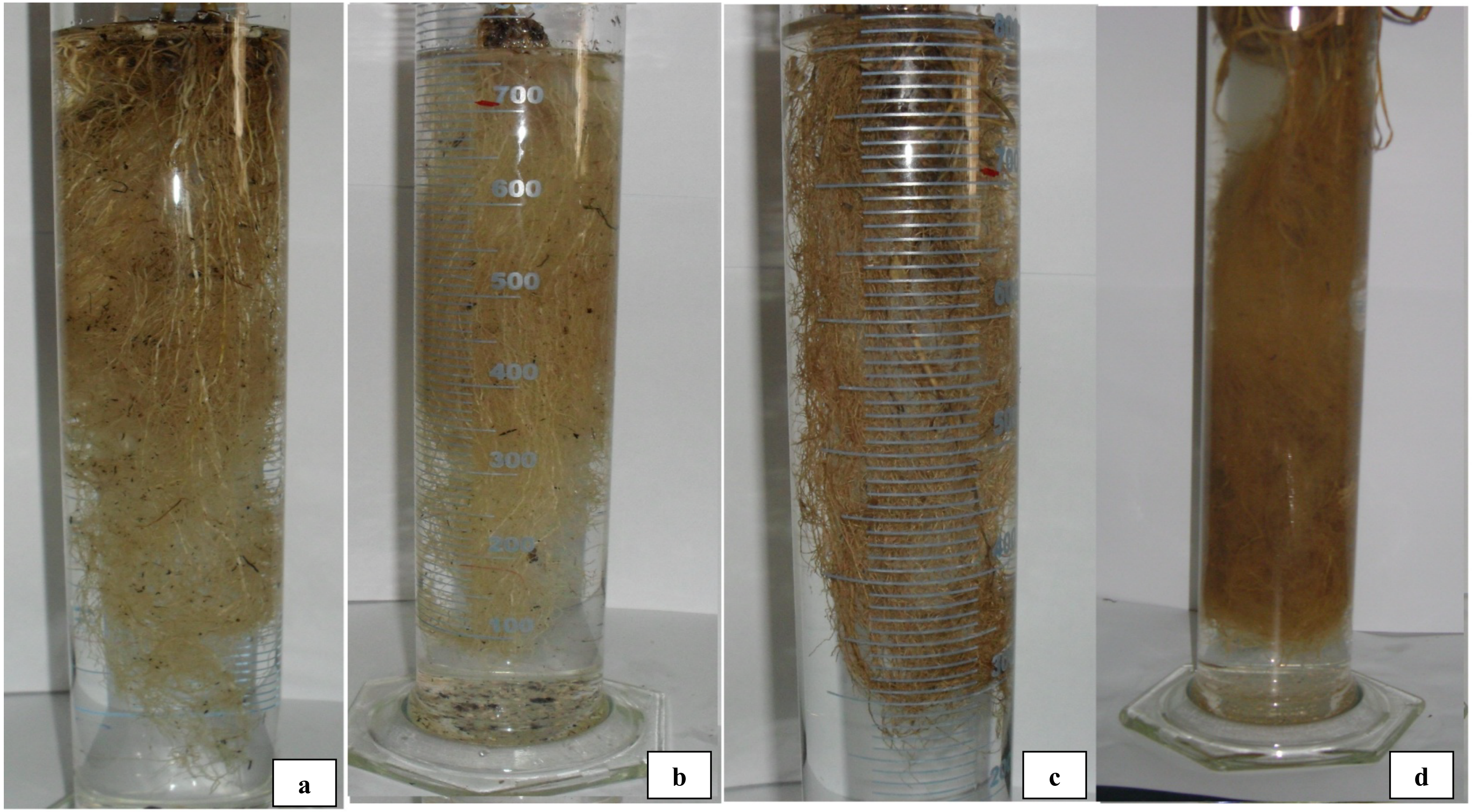


Photo 4: Root system for a. pepper, b. eggplant, c. alfalfa and d. barley.

5. CONCLUSIONS:

This study was focused on the effect of soil moisture content and plant on ^{222}Rn emission from soil to the atmosphere. The results show that both soil moisture content and plant play an important role in influencing the ^{222}Rn from soil. As the soil moisture content increases, the ^{222}Rn emission increases up to certain limit (20% by gravity), and then decreases with further increase in the moisture content. The results also show that plant cultivated pots produced ^{222}Rn radioactivity lower than that produced from the pare soil. It can be concluded that plant is effective for suppressing ^{222}Rn emission from soil to atmosphere. As a result the emission of ^{222}Rn from Russeifa dump site soil can be reduced by growing drought tolerant plants. This is a convenient practice to a country suffering from substantial shortage in fresh water supply

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تأثير نوع النبات ورطوبة التربة على انبعاث غاز الرادون من التربة

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ملخص

يعتبر غاز الرادون من المصادر الإشعاعية الهامة التي يتعرض لها الإنسان والتي يمكن أن تنبعث من الصخور التي تحتوي على عناصر مشعة مثل عنصري اليورانيوم والثوريوم وبخاصة صخور الفوسفات. هذا البحثِ يهدف لإسْتِكْشاف الإمكانيةِ مِنَ تخفيض انبعاث غاز الرادون مِنْ التربةِ إلى الجوِّ بالإفتِراض بأنّ ملء مسامات التربة بالرطوبة و/ أو تغيير حجم مسامِات التربة وتوزيعها عن طريق زراعة أنواع من النباتات ذات أنظمة جذرية مختلفة (فلفل، باذنجان، برسيم وشعير) سوف تُؤثّر على إنتشار غاز الرادون مِنْ التربة إلى الجوِ.

تم أخذ عينة تربة سطحية (0-20 سم) من مخلفات مناجم الفوسفات في مدينة الرصيفة معروف بإحتوائها على تراكيز عالية من المواد المشعة . جففت عينة التربة هوائيا, وتم تنخيلها بمنخل 2 ملم وخزنت للإستعمال التالي. لدراسة تأثير النبات على انبعاث غاز الرادون من التربة أخذت عينات جزئية من التربة المنخلة "16 كغم لكل عينة" ووضعت في قوارير بلاستيكية وزرعت بأنواع مختلفة من النبات ثم وضعت كل قارورة داخل صندوق بلاستيكي لمنع تسرب غاز الرادون المنبعث من التربة، وتم قياس النشاط الإشعاعي لغاز الرادون المنبعث من التربة المزروعة بنباتات مختلفة أسبوعيا بإستخدام كاشف الحالة الصلبة للمسارات النووية والمعروف تجاريا بإسم (CR-39).

تأثير رطوبة التربة على انبعاث غاز الرادون من التربة تم دراسته أيضا. تم أخذ عينات جزئية من التربة المنخلة "1كغم لكل عينة" وتم تجفيفها بالفرن على درجة حرارة 105 درجات مئوية ووضعت في عبوات بلاستيكية وتم اضافة كميات مختلفة من الماء (0%، 5%، 10%، 15%،20%، 25% و 30% من وزن التربة الجافة), ثم وضعت كواشف الحالة الصلبة للمسارات النووية لقياس النشاط الإشعاعي لغاز الرادون المنبعث من التربة داخل العبوات البلاستيكية وتم اغلاق العبوات بإحكام لمنع تسرب غاز الرادون الى الخارج.

أشارت النتائج الى مايلي:

1. انبعاث غاز الرادون من التربة الى الجو يزداد خطيا بإزدياد المحتوى المائي للتربة حتى حد معين (20% من وزن التربة الجاف) مابعد ذلك يقل معدل الإنبعاث لمستوى ثابت تقريبا (940 Bq m^{-3}).
2. انبعاث غاز الرادون من التربة المزروعة اقل من التربة الغير مزروعة.
3. انبعاث غاز الرادون من التربة المزروعة بنبات الفلفل اقل من انبعاثه من التربة المزروعة بالنباتات الأخرى.